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Sampling the Oceans for Pollution
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Research Strategy for Marine Waste Disposal

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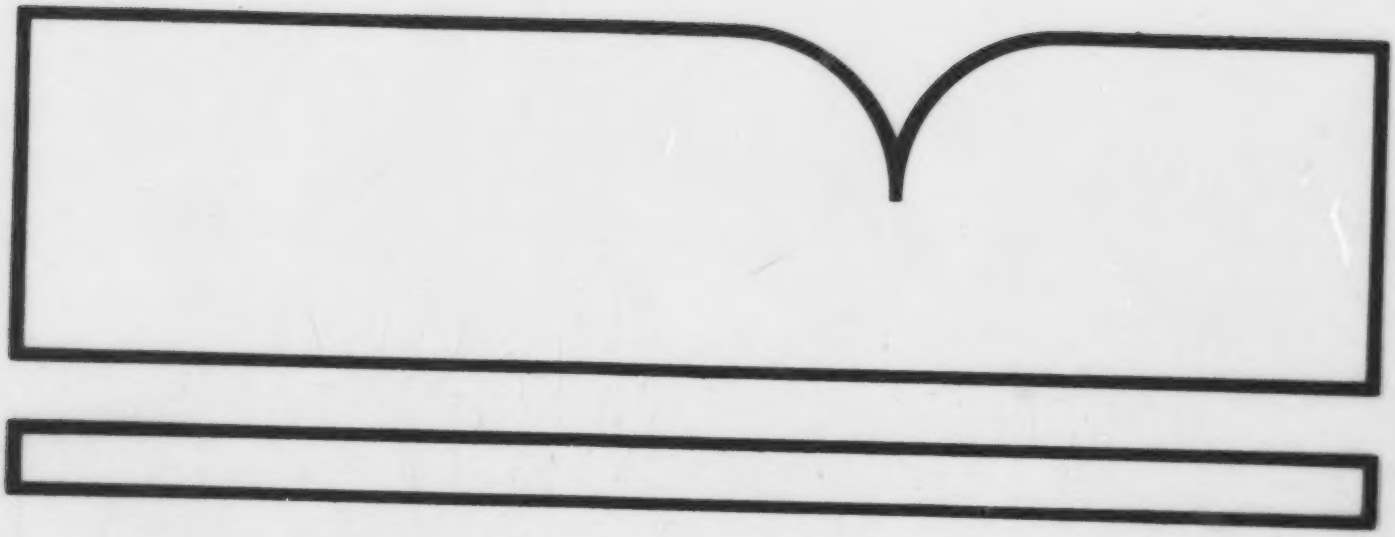

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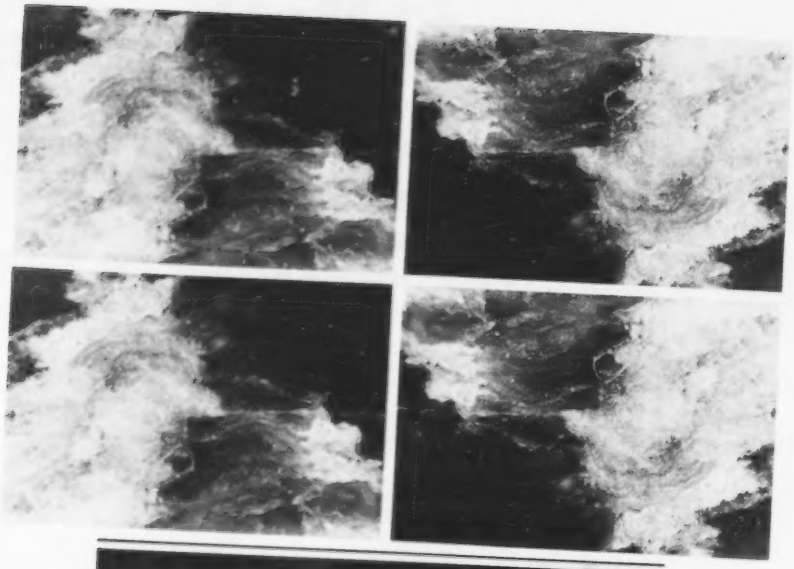

Sampling the Oceans for Pollution

EPA Research Strategy for Marine Waste Disposal

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16. ABSTRACT

This article describes EPA's current approach to the management of ocean disposal. The physical and biological characterization of a proposed site is used to gauge the liklihood of exposure of a marine resource to a waste of given characteristics. After determination of the effects of the waste component(s) on the resource(s), a "Hazard Assessment" can be made. Trial applications of this approach are described.

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BACKGROUND

Status of Marine Disposal Science

Marine environments accept billions of tons of dissolved and particulate matter annually, and large quantities of our industrial society's degradable and persistent materials. Most of this takes place at the shorelines and where fresh waters empty into the seas. The gross consequences of pollution are known in every urban estuary and coastline along our shores. There are less obvious effects as well, such as edible fishes' contamination with pesticides, which research and monitoring have demonstrated over the past several decades. Now, in the 1980's, we find ourselves with scarce research and monitoring resources with which to understand the influence of waste disposal in salt waters, and far to go before we can predict the effects of a specific waste disposal practice on a given marine disposal site. The 1980's are a time of synthesis—a time to reexamine the data at hand, see what new understandings can be gleaned from them, and consider carefully what further information will be required to predict the consequences of salt water disposal of wastes with adequate certainty. It is toward these goals and with these limitations upon us that we develop research strategy to attack the problems of marine waste disposal.

Science has been active in marine pollution research over the past four decades, in spite of the facts that (1) during the most recent past barge dumping of wastes into the oceans, estuaries, and coastal waters was either forbidden or severely regulated, and (2) piped and non-point sources of waste effluents to estuaries and coastal waters are controlled by regulations of the Clean Water Act. We have learned from studies of persistent and nonpersistent pollutants. Research and monitoring conducted at our federal laboratories, universities, and research foundations has helped us to manage power plant effluents, river outflows, sewage discharges, dredge and fill operations, sport and commercial fisheries, and environmental impact assessments. Pure academic research has advanced physical, chemical, and biological oceanography. Clearly, we are starting from a base of considerable information. Now what we need are methods to synthesize and interpret existing information and new findings so that predictive assessments of proposals to dispose of wastes in marine waters can become practical for EPA's regulatory use.

EPA's Research Role in Marine Pollution

EPA's primary roles in marine pollution research come from the Clean Water Act (PL 92-500, sections 402 and 403), and the Marine Protection Research, and Sanctuaries Act (PL 92-532, Title I, section 102, and Title II, section 203). The legal tests that these acts set forth require that EPA study ecological criteria for application to permits which both EPA and the Army Corps of Engineers (in the case of dredged materials) administer. Information asked for specifically includes criteria to determine that dumping "will not degrade or endanger human health, welfare, or amenities, or the marine environment, ecological systems, or economic potentialities." EPA is also charged to develop "disposal methods as alternatives to" ocean dumping, and to designate sites where wastes can be dumped at sea. Thus, EPA has a major commitment to marine pollution research. This includes studies of organic analytical chemistry, genetic toxicology, bioassay, microcosm ecology, histopathology, marine ecology, and engineering sewage treatment for marine discharge. Development and verification of environmental assessment methods peculiar to specific industries that discharge various wastes into marine waters either directly or through municipal sewage outfalls has been going on since the 1950's and must continue as new industrial processes are invented.

EPA intends to develop useful, scientifically credible methods to predict or assess the effects of wastes dumped or piped anywhere into the marine environment. These methods are to be used at appropriate levels of resolution for dumpsite designation, discharge permitting, and compliance monitoring. Other agencies and private entities are also expected to benefit from the availability of these methods.

Under the Ocean Pollution Research, Development, and Monitoring Planning Act (PL 95-213), all federal agencies whose mandates include marine pollution oversight are required to share and coordinate their research resources, information, goals, data, and data repositories. No agency mandates were changed, but all federally supported marine pollution research and monitoring were catalogued and coordinated among supporting agencies. This has resulted in considerable economies, lessened unintentional duplication, and most important, considerable internal recognition on the part of each regulatory agency having marine jurisdictions that it is not alone.

EPA shares marine pollution research authorities and data with NOAA's National Marine Fishery Service and National Ocean Service, the Corps of Engineers, U.S. Geological Survey, Nuclear Regulatory Commission, Bureau of Land Management, U.S. Fish and Wildlife Service, and in lesser ways with a number of other executive agencies. EPA depends heavily on NOAA and the U.S. Fish and Wildlife Service for knowledge of endangered species ecology, fisheries assessments, plankton abundance, resource distribution, and species identification. EPA depends upon NOAA

for mapping ocean bottom features and currents, as well as for certain satellite information on weather and oceanic changes that are measured by remote sensing. Information from these sources will be used extensively by EPA in its research on marine waste disposal. Research on physical and numerical modeling of transport processes in marine waters is a major interest of the Corps of Engineers, which shares its research data and cooperates in research efforts on dredged spoil removal and disposal with EPA. The Corps also conducts studies of land alternatives to marine disposal of dredged materials and certain other wastes. EPA turns to state agencies for information on microbial contamination of coastal waters, and to the U.S. Food and Drug Administration for data on chemical and microbial contaminants of edible marine species.

EPA contributes information to marine pollution studies in which we share common interests with other federal agencies and certain state agencies as well (particularly in those states to which EPA has delegated its permit issuing authority). EPA research on environmental exposure assessment methods will contribute to NOAA's predictions of fishery production for fisheries that extend into polluted waters. EPA is consulted by the Department of Interior in evaluating possible harm of an offshore oil platform accident. EPA's knowledge of ecological and species level damage done by sewage sludge discharged from ocean outfalls will contribute an empirical and scientific basis to marine disposal research.

Marine Disposal Research Objectives

The primary objective of EPA's marine disposal research is to predict the harmful consequences (hazard) involved in disposal of known wastes at known sites. We must be able to assess the hazard in terms of the likelihood of discharged waste dispersal (or containment) and in terms of the likelihood of the waste causing harm to marine resources within and beyond the site. The intent is to permit public policy decisions to be reached by application of a scientifically sound protocol which uses this information. To be thorough, our identification of research tactics began with a decision protocol to evaluate an application for ocean disposal of waste. We considered what elements are needed to conduct such a process and the basic areas of information required to assure mandated environmental protection. They are the following:

- Site characterization
- Waste characterization
- Exposure assessment
- Effects assessment
- Hazard assessment

The next step is to match what we need to know in each of those areas with what we do know. The complexity is that much of the information in hand has been gathered for other purposes and is not now in a form that can be applied immediately to the National Pollutant Discharge Elimination System (NPDES) or Ocean Dumping permitting process. Thus, we really do not know yet whether the data at hand are fully useful, and whether they can be made useful. Some them are, undoubtedly. We need to know which these are, and what is wrong with the rest. We also need to know some of the mechanics of how to characterize a waste most effectively in terms of cost, speed, and methods, and how to characterize the optimal disposal site for a given set of waste characteristics. Further, the studies of effects assessment and exposure assessment are just now developing a scientific basis. The remaining task is to complete the development of a scientific protocol for hazard evaluation as it applies to marine waste disposal. The tactics that we are pursuing are designed to lessen areas of uncertainty, while steadily improving the agency's ability to evaluate marine waste disposal applications rapidly and objectively.

RESEARCH TACTICS

Site Characterization Studies

Description of a disposal site requires that we understand its variation in hydrographic characteristics, its usual physical fluctuations that affect stratification and flow, its physical and chemical changes due to storms and periodic natural catastrophic events, and the value and vulnerability of its ecological populations and community. Physical oceanographic data on currents, circulation patterns, water mass movements, waste field behavior, stratification and destratification, density and temperature regimes, site depths, and bottom substratum composition all must be known to attempt predictive modeling of waste transport and possible exposure of marine life.

Chemical information is necessary to the characterization processes. Water salinity, background concentrations of natural and contaminant chemicals in the water column and in bottom sediments, presence of toxic chemicals in flesh of indigenous plants and animals, and elements which trace water masses as they move about are all important considerations in choosing optimal sites for marine disposal of wastes.

Biological information on indigenous water column, bottom dwelling and area dependent species' abundance, distribution, condition, disease incidence and distribution, and vulnerability to the particular

wastes proposed for disposal is also essential to assess suitability of the site for possible waste disposal. Most useful categories of plants and animals for these purposes in EPA's consideration of municipal waste treatment waiver applications [section 301(h), PL 95-217] are phytoplankton, zooplankton, attached algae, epibenthic invertebrates, benthic infauna, and commercially and recreationally important species. Distinctive habitats of limited distribution such as coral reefs and kelp beds are given special consideration because they are highly vulnerable to pollution damage. Endangered species are also given special status by law, and that too must be reflected in assessment of the site. Most of these biological categories are applied to ocean dumping studies as well.

Waste Characterization Studies

Domestic wastes that do not contain sewage sludges or contaminants in toxic concentrations are eligible for NPDES permission to be discharged through ocean outfalls. Also, there are three general categories of wastes that are eligible to be considered for barged waste disposal. These are dredged materials, municipal sewage sludges, and industrial materials that are not categorically or individually forbidden by law. Any material that is to be transported to sea for disposal must be demonstrated (to the satisfaction of EPA) not to cause unreasonable degradation of the marine environment. Each of these eligible waste categories has unique properties that must be considered in developing disposal protocols. These are their physical properties which control dispersive characteristics, chemical properties of toxicity, and potential for contaminant residues which influence the degree of hazard.

Information necessary to determine physical dispersion and fate of the waste include its density, particle size, sedimentation rate, deposition depth, suspension and resuspension potentials, and rate of decay. Together with site characterization information (above), these data make it possible to estimate the transport and dispersion of waste in and around the disposal site, and thus to evaluate the likelihood of exposure of living marine resources in the area under consideration. In fact, the determination of transport and dispersion of the waste defines the spatial extent of concern for the disposal site's influence on its environs.

Chemical analysis of the waste is required first to determine eligibility of the material for ocean disposal. Prohibited materials include high-level radioactive wastes, mercury in high concentrations, biological and chemical warfare agents (not all of which are produced for purposes of warfare), and high concentrations of "priority" pollutants (listed by EPA in the Federal Register).

The analytical conundrum is that toxicity is the interaction of a chemical with an exposed animal, and we are dealing with a mixture of chemicals and a spectrum of indigenous animals. Biological assays of the waste in question upon representative, important species indigenous to the site, are usually employed to address the toxicity issue as well as the bioavailability, bioaccumulation, and bioconcentration concerns which may apply. Therefore, waste characterization must proceed conceptually to consider the effects issue; at least to emphasize harmful materials over those which are benign. Work on improving chemical analyses of mixed wastes in marine media is proceeding in parallel with these research tactics—and is not discussed here beyond the statements that (1) the greatest problems to be overcome are standardizing source biological materials and sediments for pollutant analysis, and (2) inventing applicable chemical analyses which are low enough in cost so that sufficient numbers of samples can be analyzed to provide a statistically valid basis for verifying the finished hazard model.

Exposure Assessment Studies

Exposure assessment is the determination of likelihood that the pollutant disposed of at sea will contact the resource which is to be protected. Exposure assessment requires that the amount of waste contacting the resource, as well as the duration of contact, be known. Concentration as a function of time represents exposure. Such information may be measured directly when dealing with an existing outfall pipe or an ongoing ocean dumping operation, but in other situations we are forced into a predictive mode because the proposed waste discharge and the critical resource may not always be at the same location. Such prediction is done best by mathematical modeling of the various physical, chemical, and biological processes which can influence the transport, transformation, and ultimate fate of the pollutants.

Mathematical models express the relationships among three dimensional hydrographic characteristics such as advective flow, dispersion of suspended solids, and pollutant interchanges between the water column and sediments. Models also express relationships among physical, chemical and biological transformations, and movements of pollutants in the waste throughout the water column, sediment, and biota. Such parameters as adsorption, desorption, degradation, oxygen demands, and bioaccumulation are expressions in these equations.

Models themselves have different uses depending upon the spatial and temporal resolution that is required for the decision at hand. Therefore, a hierarchy of models is planned, organized on the basis of space,

time, and environmental compartments (e.g., water, sediments, biota) under consideration. At high levels of resolution, the model relates specific physical, chemical, and biological processes in each compartment. The degree of specificity of the models will vary depending upon the needed resolution. The resolution needed governs the model's complexity and detail.

Effects Assessment Studies

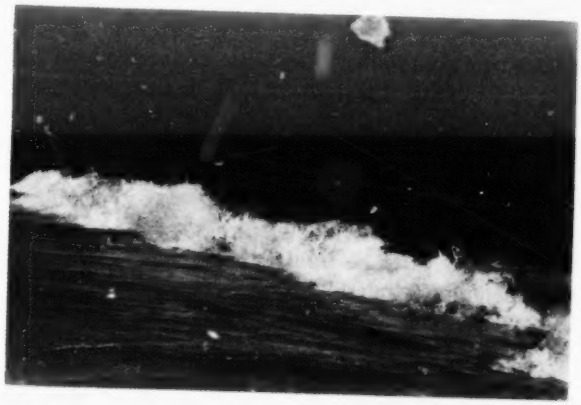
Biological components of a hazard assessment for marine waste disposal are perhaps those most open to disagreement because the ultimate concern is for the whole ecological community (except for endangered species and distinctive habitats of limited distribution which generally are agreed to require special consideration). Biological vulnerability studies available are mostly single species laboratory bioassays. More recent studies are multiple pollutant, single species laboratory bioassays, and field exposure of single species to single or multiple discharge insults. Many of these studies were intended for evaluating existing inshore conditions and were not designed for open ocean application of results. Most recently, variously sized microcosms have been constructed and studied under unperturbed and polluted conditions. These studies are still in developmental stages and have not been employed in permitting decisions. However, choosing the most applicable biological exposure conditions is part of the hazard modeling effort. Diverse methods are under consideration for adaptation, revision, and development for application to marine dumpsite evaluation, and no reasonable method will be ignored as a candidate.

The ultimate criterion of acceptance for a biological test for vulnerability to a waste is that the method must produce a result that can be verified at the disposal site. On-site verification measurement of chemical and physical predictions is necessary and planned. Verification of biological screening tests and predictive methods is expected to be most difficult, partly because of natural variability of ecological communities which in turn respond to natural variability in physical and chemical properties of seawater environments.

Hazard Assessment Studies

Hazard assessment itself is the collection and synthesis of information on the waste's characteristics, the site's characteristics, the biological, physical, and chemical processes which affect the fate and transport of contaminants, and the vulnerability of the biota of concern. It is the combination of exposure assessment with effects assessment; relating the characteristics of the system to each other in such a way as to predict the likelihood of known consequences (the hazard) to the environment. Ideally, this should be a mathematical expression of these relationships, but this remains more a goal than a reality at our present state of knowledge.

A hierarchical nesting of models would allow both near field and far field predictions of the consequences of waste exposure to the marine resources. This is the ideal we seek in hazard assessment. "Hazard" in the predictive sense is a function of combining the likelihood that an exposure will occur with the likelihood that a consequence will happen. Hazard is the endpoint that we need to determine. The hazard of environmental consequences is the major scientific criterion for approval or disapproval of a request to dispose of waste at sea. It is the objective criterion that can be provided by marine scientists to those who must decide these matters.



Problem Areas for Research

Recall here that we set out to develop methods to predict or assess the effects of waste disposal in the marine environment. We have called this hazard assessment. Hazard assessment is achieved by combining the likelihood of the pollutant reaching a vulnerable resource with the likelihood of an effect occurring as a direct consequence of that contact. In a prediction, each of these likelihoods is associated with a statistical uncertainty due to chance or error. The combination of exposure and effect likelihoods compounds the combined uncertainty, making it greater. An ideal hazard assessment prediction must have a known and acceptably small uncertainty. Reaching a scientifically acceptable certainty in our predictions is the goal of hazard assessment research.

To allow assessment of risking an effect from an exposure, we chose a measurement system which uses common units. This is done by stating the exposure (to a concentration of pollutant over a duration of time) and expressing effects in concentration terms. Hazard is then defined in terms of the concentration needed

to produce the unwanted effect. This allows hazard assessment for a single condition to proceed on a statistically testable basis, since both exposure and effect are stated as concentrations of pollutant. Effects which can be determined experimentally in the laboratory or by direct measurement at sea thus become useful in predicting and managing environmental risk. Mathematical modeling of concentration distributions allows us to delineate the areal or three dimensional extent of a chosen hazard. Overall, the assessment is easier said than done.

The difficulties in using this system are reaching agreement on what condition shall be chosen to represent unacceptable environmental risk, and how much uncertainty is acceptable in the determination. Agreement on choice of an unacceptable condition is an administrative rather than a scientific consideration. So is acceptance of less than a 95% certainty that the data are not due to chance or error. When we come down to a single application of hazard assessment, hazard uncertainty still expands by the amount that error propagates and compounds through all of the assessment protocols followed. However, at present this compounded uncertainty is the best that science can offer to hazard assessment protocols. It is not necessarily the best that science will ever be able to do.

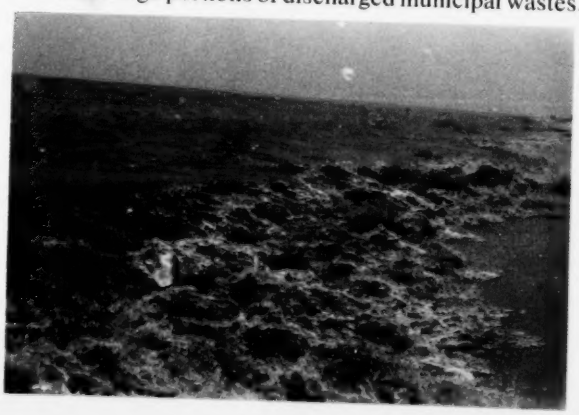
One major research problem we should address is the improvement of the confidence that can be had in the combination of exposure and effects probabilities. There are two statistical approaches to setting overall confidence limits for a hazard assessment protocol. The first, easiest, and most accessible is the empirical method—in which a number of hazard assessment combinations of exposure and effects probabilities are analyzed statistically to yield the actual confidence that can be had in experience. If experiences are broad enough across the spectrum of marine waste disposal situations, and numerous enough, then we may infer ever better predictive confidence (i.e., ever lesser amount of uncertainty). There are even statistical methods to improve the confidence in certain properly sampled situations' outcomes, such as the Monte Carlo analysis. This method uses a spectrum of distributed results to calculate a range of "chances of occurrence," and includes statistical testing of the adequacy of the outcome predictions.

We have begun hazard assessments in several ways. These involve derivation of baseline environmental conditions, compliance monitoring, and integrations of these efforts to produce field validation of effects predicted from laboratory or mathematical models. So far neither exposure assessment nor effects assessment protocols have progressed to the point at which individual probabilities of either can be determined with acceptable levels of certainty. Preliminary tactical trials described below are designed, among other purposes, to solve this problem.

The second approach—more difficult, but most desirable scientifically—would be to develop new statistical treatments of our assessment protocols that will improve the certainty which may be achieved for hazard predictions. Probabilities of two events (e.g., exposure and effects) cannot now be combined with a scientifically satisfactory degree of certainty. There is a practical limit to the amount of precision and accuracy improvement possible in our field and laboratory measurements. Increases in certainty achieved by narrowing the scope of investigation also narrow the applicability of results, which is counterproductive in setting public policy. We have not begun a research investigation into statistical methods to improve the certainty of hazard assessment protocols for marine pollution predictions, as we are still involved in deriving separate exposure and effects assessments which themselves are statistically acceptable. We are starting to think about it though.

PRELIMINARY TACTICAL TRIALS

EPA's Narragansett Environmental Research Laboratory and the Corps of Engineers' Vicksberg Waterways Experiment Station are cooperating on a dredged materials study in Long Island Sound which is intended as a test of these marine waste disposal research tactics. The issue at hand is real—what are the environmental consequences of barge dumping materials dredged from Black Rock Harbor. The question is, "which types of assessment methods should be used as part of a general predictive hazard assessment protocol useful for other wastes and sites." The issue is also real in the sense that Black Rock Harbor is not a perfect research situation. There is an existing dumpsite which has a history that is incompletely known. It is not an open ocean dumpsite. It receives considerable water from western Long Island Sound which contains large portions of discharged municipal wastes,



not only from the western Sound municipalities, but also from the East River which borders New York City. One New York City plant alone contributes a hundred million gallons or more per day of primary treated sewage to the western arm of Long Island Sound. Most important, it is a site which EPA and the Corps need immediate information about, in order to manage waste disposal. If our research tactics can provide useful and quantitative hazard assessment in this difficult setting, then we may be confident that they are sound and worthy of testing elsewhere.

Results of the Long Island Sound cooperative research on waste disposal will be published as they warrant in several scientific and public forums. The project is mentioned here as an example of applied, ordered research tactics. Site evaluation is well underway, based on considerable information about Long Island Sound hydrography, biology, and water quality. Waste characterization is progressing in the analytical chemistry laboratories at Narragansett. Exposure assessment models are also being developed and field validated in terms of effects levels at the Narragansett Laboratory. The Corps is studying upland disposal of dredged material from the Harbor and its water quality effects at the shoreline. Biotic surveys of the whole dumpsite, the particular portion of it to be used, and a reference site some four miles away to be used for comparison are also underway and will form the basis of an effects assessment. When all of the data are in, and the exposure and effects assessments are completed, tested against their own assumptions, and verified on-site, then the hazard assessment can be completed and tested on-site as subsequent dredgings and dumpings of dredged material take place. This will provide an empirical basis for tests of the hazard assessment protocol at other places, which will in turn enhance our ability to manage marine waste disposal according to scientific principles.

RESEARCH PRODUCTS

EPA's research into marine waste disposal and its alternatives is a matter of establishing new information and developing a framework for organizing and interpreting it. To make our research useful, we must disseminate information to the scientific community and the public as well. Anticipated products of marine waste disposal research included in the Agency's tactics are: seminars, lectures, peer review forums, progress reports, technical guidance documents on marine waste disposal assessment and monitoring, scientific journal papers, contributions to marine waste disposal regulation revisions, testimony at permit and oversight hearings, training workshops for regional and state regulatory personnel, participation in interagency Planning sessions, authorship of essays and book chapters on marine waste disposal, and collaborative studies with private sector scientists. Using these information outlets, we hope to create a climate in which reasoned public policy decisions on uses of the marine environment will become *pro forma* happenings, and both EPA's applicants and the public can anticipate its regulatory actions based upon the circumstances in question. We see no reason why these goals cannot be achieved by the end of the next decade.

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